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Optimizing Supplier Selection for a Construction Project by a Cash-Flow Approach Using a Hybrid Metaheuristic Algorithm

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Abstract

Supplier selection is the practice of evaluating and selecting the best or most suitable supplier for the organization based on the candidates' qualities and qualifications. In large construction projects, supplier selection strongly impacts the quality of materials as well as the cash-flow and logistical support of the project. The issue becomes particularly important when a high number and volume of orders and a varied set of items are involved. If the procurement process is organized into several periods, the impact of Net Present Value (NPV) on the project's overall profit or loss becomes significant, as well. In this study, the solution to a multi-product multi-period supplier selection optimization problem is evaluated using a hybrid metaheuristic algorithm and considering the cash flow. Our analysis of the results shows that the algorithm is able to obtain the intended outcome within an appropriate timeframe and with high precision.

Keywords: Optimization, Supplier selection, Metaheuristic algorithm, Net present value.

1 | Introduction

In recent decades, ways of improving integrated supply chain scheduling models, which include various sub-supply chains such as logistics and production, have been drawing a great deal of attention [1]. With the growing competitive pressure, organizations have widely focused on carrying out their primary, strategic activities themselves and outsourcing their secondary activities. In light of the increasing prevalence of outsourcing, supplier selection decisions have gained more significance. Given the various complexities of construction projects, supplier selection in this field is arguably more important than most others because even the suppliers of ostensibly minor parts of a construction project may directly impact the success or failure of the entire project in terms of cost, time, and marginal profit. Supplier selection, in simple terms, refers to the practice of evaluating, and ultimately selecting, the best or most suitable supplier for the purposes of an organization based on the candidates' various qualities, capabilities, and qualifications. In supplier selection, the problem

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starts by compiling a list of potential suppliers, then the best possible group – or package – of suppliers is selected, and lastly, an optimal number of orders is assigned to the selected candidates [2].

As far as general contractors are concerned, budget allocation and financing form one of the key aspects of any construction project. Failure to set the right budget can result in financial damages and cause the contractor to suffer a loss [3]. Conversely, proper and systematic management and financing of projects brings contractors the intended profit. Thus, contractors need to secure sufficient funds for their respective projects from various sources, such as bank loans, to be able to drive the projects forward in the right conditions. When projects are financed appropriately, the contractor can rest assured that their debts will not exceed the maximum credit limit [4]. It is imperative to consider the liquidity conditions of the project in a careful and timely manner when selecting the raw material suppliers. This is especially true in the case of large-scale, complex projects where there is more emphasis on the sequence of activities.

2 | Research Background

In the present study, the existing literature on the subject is reviewed and discussed in four categories: 1) supply chains and supplier selection, 2) contractor selection in construction projects, 3) optimization using evolutionary algorithms, and 4) cash-flow-based optimization.

2.1 | Supply Chains and Supplier Selection

Since Houlihan [44] introduced Supply Chain Management (SCM) in 1988, the concept has been drawing increasing attention. Although SCM has consistently grown in popularity among both executives and scholars alike, there is as yet no definition for the concept on which experts can reach a consensus. Perhaps the most comprehensive, widely-accepted definition has thus far been proposed by Simchi-Levi, stating that SCM refers to a set of approaches taken to effectively integrate suppliers, manufacturers, depots, and retailers to ensure that products are manufactured, stored, and distributed in the right place at the right time, such that the highest possible service-level is achieved with minimum total cost [5].

There are four major approaches to selecting the supplier(s) of a supply chain: Multi-Criteria Decision-Making (MCDM), Multi-Objective Decision-Making (MODM), statistical-probabilistic approaches, and intelligent approaches, among others.

Weber et al. [2] produced a review research of the existing quantitative methods to the supplier selection problem. According to the results, linear weighting models, mathematical programming, and statistical-probabilistic approaches were the most widely-used of all approaches. Nydick and Hill [6] and Akarte et al. [7] demonstrated the way the Analytic Hierarchy Process (AHP) could be used to select the suppliers. In addition to the regular AHP, the fuzzy AHP has also been proposed as a viable method by many scholars throughout the years [8], [9]. Weber and Current [10] worked on multi-objective programming approach to help purchasing and procurement managers with their decision-making. Weber et al. [11] used the same approach to expand upon their previous work.

Ghodsypour and O'Brien [12] proposed a model that integrated the AHP and linear programming to select the best candidate supplier. De Boer et al. [13] presented a new review research on the existing supplier-selection approaches of the time. The authors showed that various methods were available for this purpose at the time, including but not limited to Data Envelopment Analysis (DEA), total cost approaches, linear programming, linear weighting models, statistical methods, and intelligent artificial models. A few examples in this regard are the expert system model presented by Vokurka et al. [14], DEA models created by Weber [15] and Liu et al. [16], and the total cost approach proposed by Ghodsypour and O'Brien [17]. Bhutta and Huq [18] used two approaches, one based on AHP and the

other on the Total Cost of Ownership (TCO) to select the supplier and compared the results generated by each approach.

In general, supplier-selection problems have been addressed by researchers either in single-objective or multi-objective modes. In most single-objective models, the main objective has been to minimize the costs (such as the cost of procurement, cost of ordering products to a supplier, inventory cost, etc.). Moreover, in single-objective models, one criterion is set as the main objective and the other criteria are treated as constraints. Nonetheless, failure to consider the impact of the Net Present Value (NPV) of marginal profit as a significant factor may indeed be regarded as a research gap in this field.

2.2 | Contractor Selection in Construction Projects

In the model proposed by Singh and Tiong [19], the candidate contractors were assessed based on three main criteria: proposed price in tender, past performance, and current capabilities. Lam et al. [20] proposed a model based on the Support Vector Machine (SVM) and, based on a thorough review of the prior research, used factors such as financial power, past performance and experiences, and equipment as the input of their model. Jaskowski et al. [21] based their evaluation of their model on a case study and highlighted human resources, equipment, overall ability, and financial capacity, among other, as significant factors. Lam and Yu [22] developed a model and considered a number of evaluation criteria, classified under the two categories of qualitative and quantitative criteria, as the model's input. Plebankiewicz [23] proposed a model in which time, cost, and quality were considered as the cornerstones of the project. San Cristóbal [24], whose study was based on a case study, considered many criteria including price, end date, and technical qualification.

The increasing complexity of today's projects have led to a growing tendency toward hiring Engineering, Procurement, and Construction (EPC) contractors. In simple terms, EPC contractors take complete charge of a large project and outsource each part and/or phase of it to other contractors. Thus, in light of the studies introduced above, it is clearly quite important to select the suppliers and contractors of any project in a way that each phase of the project is manageable for EPC contractors in terms of financing and cash-flow. However, there are currently very few studies in the literature to have considered such concerns in their problems and models.

2.3 | Cash-Flow Optimization

In a seminal work in the field, Elazouni and Gab-Allah [25] introduced the finance-based scheduling approach. Since then, numerous studies have adopted the approach to deal with similar problems. They also developed an augmented version of their original approach to generate financially feasible schedules. Elazouni and Metwally [4], [45], Ali and Elazouni [26] and Abido and Elazouni [27] worked on techniques based on Genetic Algorithms (GA) to devise schedules that would minimize the total cost and duration of the project under a fixed liquidity. Our review of the literature indicates that although marginal profit has a considerable impact on cash-flow optimization, it remains a relatively underresearched area.

2.4 | Optimization Using Evolutionary Algorithms

There are various search methods in optimization problems. However, all these methods can be classified into three broad categories: 1) mathematical methods, 2) heuristics, and 3) metaheuristics. Kelley Jr. [28] modeled the time-cost trade-off optimization with the assumption of there being a linear relationship between the required time and cost of the activities. Other studies [29], [30] also utilized linear programming as a means of optimizing the time-cost trade-off. However, given the high number of activities in each project, evaluating all the possible solutions within a small timeframe at a reasonable cost is virtually impossible. The method proposed by Fondahl [31], Prager's [32] structural model, Siemens' [33] CPM cost model, and Moselhi's [34] direct stiffness method, are examples of the use of heuristics which generally produce good (but not necessarily optimal) solutions.

El-Rayes and Moselhi [35] presented a metaheuristic algorithm to schedule repetitive activities under the assumption of having limited resources. Leu and Yang [36] used a multi-criteria GA to devise an optimized schedule which integrated the time-cost trade-off, resource constraints, and resource leveling. El-Rayes and Jun [37], Hegazy [38], and Chan et al. [39] solved the resource-leveling and resource-allocation problems using GAs. Hartmann [40] and Zhang et al. [41] adopted a GA and the Bird Swarm Algorithm (BSA), respectively, to solve a scheduling problem with resource constraints. El-Rayes and Kandil [42] presented an improved model that enabled decision-makers to obtain an optimal resource-allocation schedule. Lastly, the model developed by El-Abbasy et al. [43] minimized the time and cost of utilizing the available resources while maximizing the quality. Employing evolutionary algorithms in complex large-scale problems may not always yield optimal solutions. Consequently, there is a tangible need for high-speed and high-accuracy algorithms to deal with such problems.

3 | Research Objective

In light of the points discussed in the previous sections with regards to developing a hybrid model for optimal supplier selection in a construction project by an EPC contractor, and considering the limitations associated with the cash-flow of such projects, the main objective of the present study is to solve this optimization problem using a hybrid metaheuristic algorithm that is able to obtain optimal solutions within a reasonable time.

Thus, the model may help answer the following two questions:

I. How to pick the best possible choices from a pool of candidate suppliers for a large-scale project while minimizing the NPV of the total project cost?

II. Is it possible to evaluate the qualifications and capabilities of the candidate suppliers within a reasonable time?

In the next section, the methodology and process of developing the model will be described.

4 | Research Methodology

In this section, we discuss each of the following sets of topics in a separate subsection at length:

I. The case study and its corresponding mathematical model, cost variables, the definition of the concept of cash-flow and its parameters.

II. The hybrid metaheuristic algorithm developed to solve the main optimization problem in this study along with its structure and execution process.

4.1 | Case Study

In this research, we examine the SC of a large-scale construction project (henceforth called "the project") as a case study. The project involves the provision of various types of raw materials at different stages. Given the logistical planning carried out in advance, the raw materials and equipment needed for the project should be procured and delivered by the suppliers at regular intervals in order to ensure that the project runs smoothly and consistently. Moreover, the particular conditions of the project dictates that the activities be performed with a logical overlap. On this basis, optimal procurement management and supplier selection are inevitable. The items procured in the project, the manner of procurement, and the suppliers for each item are summarized in *Table 1*. As the table suggests, the goal of the project is to select the optimal suppliers at the lowest possible cost. In the next subsection, we describe the mathematical model developed for the project.

Table 1. Project data

Item No.	Start-Week	End-Week	Number of Orders	Number of Candidate Suppliers
1	1	6	500	2
2	2	10	200	3
3	5	9	150	2
4	9	14	50	3
5	11	18	100	2
6	19	27	150	2
7	26	34	100	4
8	32	43	30	2
9	37	44	50	3
10	40	50	10	2

4.2 | Formulating the Model

Given the high number of items used in the project and the procurement costs involved, it is critically important to procure the required items and equipment from qualified suppliers while considering their characteristics. Clearly, any purchase should be made while considering the suppliers' capabilities and the limitations faced by the company in making the purchases from the suppliers. The assumptions, indices, variables, and parameters of the model are detailed in *Table 2* as follows.

Table 2. Characteristics, indices, variables, and parameters of the model.

Assumptions	Limited production capacity, fixed prices during each period, no raw material shortage allowed, placing at least one order from selected suppliers, controlling the quality of procured materials.
Indices	S: set of suppliers, J: set of items, T: time periods.
Variables	x_{jst}: amount of item j procured by supplier s in time period t. f_{jst}: a percentage of item j procured by supplier s in time period t which should be quality-controlled. y_{jst}: equals 1 if suppier s has been selected to procure item j in time period t; otherwise 0. NS: maximum number of suppliers selected from among candidate suppliers.
Capacity Parameters	Cps_{sjt}: production capacity of supplier s to manufacture item j in time period t. Md_{js}: minimum number of item j ordered from supplier s. d_j: demand for item j in the project.
Cost Parameters	cc_{js}: cost of closing a contract with supplier s to supply item j. hc_{js}: cost of storing item j manufactured by supplier s. qc_{js}: cost of controlling the quality of item j manufactured by supplier s. sc_{js}: cost of supplying item j by supplier s.

4.3 | Objective Functions

As can be seen in *Table 3*, the main costs involved in the process of procuring the raw material and equipment from the suppliers are related to contract signing, supply, storage, and quality control.

Contract cost mostly comprises the initial cost of closing contracts with the suppliers and can vary according to each supplier's background. The contract cost is paid one week before the first shipment is delivered.

Supply cost consists of all the costs spent by the supplier including manufacturing, preparation, packaging, and delivery of raw materials or equipment to the project site. The main difference between the suppliers in terms of price relates to this set of costs. The supply cost is paid at the time of delivery.

Storage cost includes the costs of warehousing, maintenance, etc. which are paid at the time of delivery.

Quality control cost depends on the background and quality of each supplier and is paid at the time of delivery. As a simple rule, the higher the quality of a supplier, the lower the quality control cost of and the higher the supply cost.

Table 3. Main costs of suppliers for project activities.

Activity	Number of Supplier	Supplier#1 Costs				Supplier#2 Costs				Supplier#3 Costs				Supplier#4 Costs				Supplier#5 Costs			
		Quality Control	Supply	Contract	Storage	Quality Control	Supply	Contract	Storage	Quality Control	Supply	Contract	Storage	Quality Control	Supply	Contract	Storage	Quality Control	Supply	Contract	Storage
1	2	100	1,200	120	40	0	125	1,300	140	40	0										
2	3	145	1,700	140	50	0	130	1,400	120	50	0	160	1,800	150	50	0					
3	2	50	800	80	20	0	70	1,000	100	20	0										
4	3	200	2,100	230	130	0	180	1,700	200	130	0	220	2,400	250	130	0					
5	2	400	5,000	400	300	0	450	5,500	430	300	0										
6	2	350	3,800	290	150	0	400	4,200	310	150	0										
7	4	50	500	60	20	0	70	600	80	20	0	100	700	90	20	0	120	800	100	20	0
8	2	100	1,000	130	50	0	80	800	110	50	0										
9	3	120	1,200	140	60	0	160	1,700	160	60	0	170	1,800	190	60	0					
10	2	800	10,000	900	300	0	700	9,500	800	300	0										

Given the points raised in this section, the mathematical model to minimize the total NPV of the total cost is as follows:

$$\min \quad \sum_{s\in S}\sum_{j\in J}\sum_{t\in T}NPV(y_{sjt}cc_{js}) + \sum_{s\in S}\sum_{j\in J}\sum_{t\in T}NPV(hc_{js}x_{jst}) + \sum_{s\in S}\sum_{j\in J}\sum_{t\in T}NPV(qc_{js}x_{jst}f_{jst}) + \sum_{s\in S}\sum_{j\in J}\sum_{t\in T}NPV\left(sc_{js}x_{jst}\right). \tag{1}$$

There are two time periods in the problem. The first period starts at the time of scheduling the purchases and the second one starts half-way through the project. The duration of the two periods can differ based on the orders.

4.4 | Constraints of the Model

The model's four constraints are as follows:

$$x_{jst} \leq cps_{sjt}, \quad \forall j \in J, \quad \forall s \in S, \quad \forall t \in T \tag{2}$$

$$\sum_{s \in S} x_{jst} = d_{jt}, \quad \forall j \in J, \quad \forall t \in T \tag{3}$$

$$x_{jst} \geq md_{js}, \quad \forall j \in J, \quad \forall t \in T, \quad \forall s \in S \tag{4}$$

$$\sum_{s \in S} y_{jst} \leq NS, \quad \forall j \in J, \quad \forall t \in T \tag{5}$$

Constraint (2) ensures that the number of orders from the suppliers at each period cannot exceed the maximum production capacity of that period. *Constraints (3)* sets the maximum number of orders over the two periods. *Constraint (4)* determines the minimum number of orders placed to a single supplier. Lastly, *Constraint (5)* expresses the maximum number of suppliers that can be selected from the candidate suppliers pool to supply a single item.

4.5 | Calculating the NPV

The main purpose of this subsection is to calculate the total cost of project procurement. In most cases, the contractors' profit is only obtained at the completion of the project. In cash-flow management, the total project cost refers to the sum of all outputs. However, it should be noted that outputs are generated at different points in time. Thus, calculating the NPV of the outputs can give contractors a clearer view of the project's various cost factors, help project planners to find the most suitable supplier for each item, and ultimately optimize the total project cost. *Eq. (6)* calculates the NPV as follows:

$$P = \text{Output}_j \times \frac{1}{(1+r)^j}. \tag{6}$$

Where P stands for NPV, Output_j is the cost output on date j, and r denotes the weekly interest rate.

5 | Hybrid Algorithm Proposed to Solve the Problem

Although the GA has formed the basis of the hybrid algorithms developed by most researchers, in this study we use the Shuffled Frog Leaping Algorithm (SFLA) as our basic algorithm. The SFLA is quite fast and because of the grouping of the chromosomes, it is easier for the algorithm to evaluate all chromosomes while executing the program. However, on the negative side, this algorithm does not generate the most accurate solutions and, especially with problems that have a large search space, its accuracy degrades more significantly. Consequently, it is necessary to have an auxiliary algorithm to enhance the accuracy of the obtained solutions. Moreover, the auxiliary algorithm should not increase the computation time by adding a considerable computational burden to the program. In short, an acceptable auxiliary algorithm for this purpose is one that establishes an optimal trade-off between the accuracy of the solutions and computation/execution time. The GA, one of the most widely-known metaheuristics, offers adequate computation and has highly modifiable operators. Thus, we develop a GA as the auxiliary algorithm for this problem. *Fig. 1* illustrates the structure of the hybrid algorithm. As can be seen, the execution procedure of the algorithm is classified in three general phases.

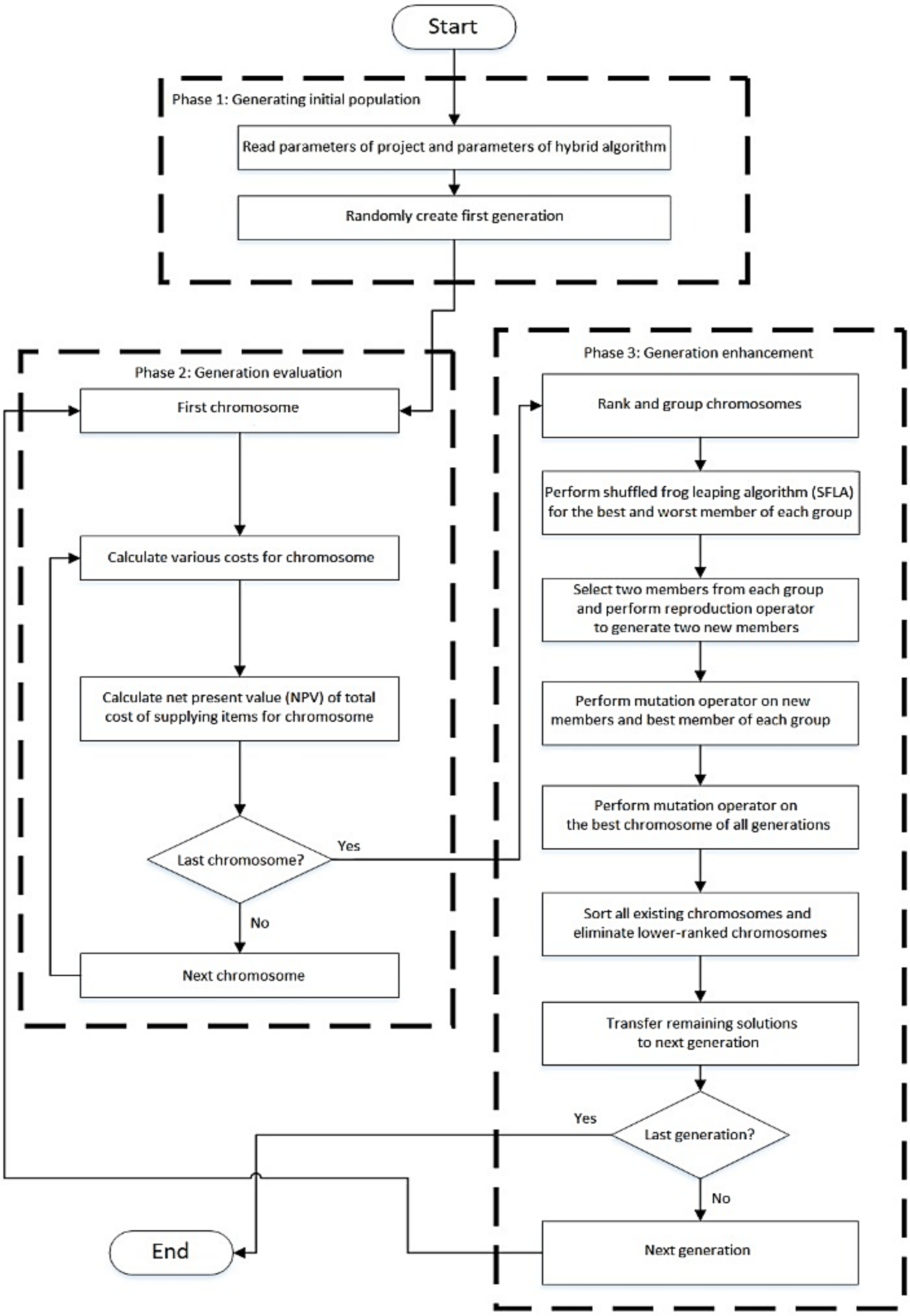

Fig. 1. Flowchart of the proposed hybrid algorithm.

5.1 | Results

Given the high complexity of the model in terms of the number of variables, parameters, constraints, and data, the model was developed in the C++ programming language on Microsoft Visual Studio. *Table 4* details the initial parameter of the hybrid algorithm developed to model the case study. As can be seen in *Fig. 2*, the value of the optimal solution (minimum cost) decreases in each generation. This reduction rate becomes insignificant in the final generations, indicating the algorithm's convergence. *Table 5* contains the results obtained from solving the model. The minimum cost of the initial generation is $10^6 \times 2.62$, which experiences a significant decrease to $10^6 \times 2.35$ in the final generation. Although the operation to compute the cash-flow significantly adds to the overall computational burden of the model, the average execution time of the model in both problems is relatively reasonable. Since there has been no research on this type of problem, judging the final solution is not simple unless exact solution software is used to compute the exact value of the solution to the problem. A comparison of the results and the percentage of deviation from the best solution indicates the high accuracy of the solutions and

thereby points to the satisfactory performance of the hybrid algorithm. Considering the specifications of the computer used in this research (CPU Core i7-6700HQ CPU @ 2.60GHz, Ram 16Gb) the total execution/processing time of 3 seconds is completely acceptable. The 60% success rate and convergence of the results also confirm that the hybrid algorithm has been successful in solving the optimization problem.

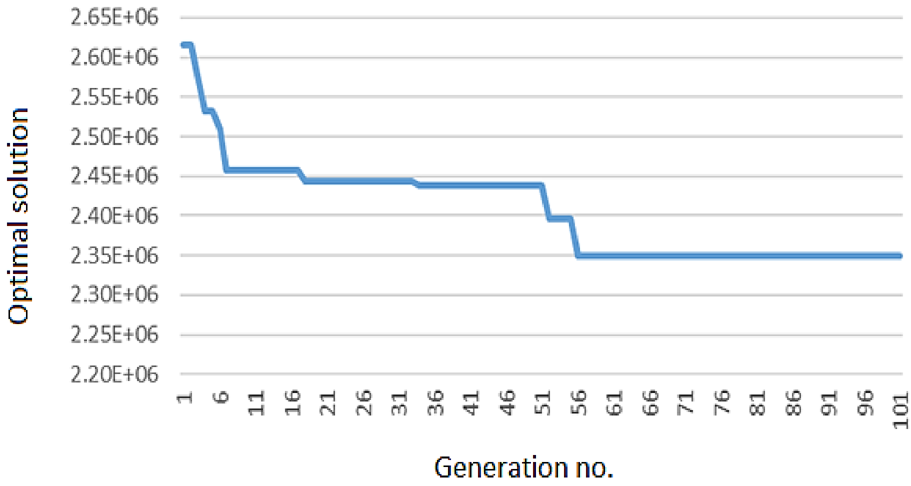

Fig. 2. Convergence graph of optimal solutions.

Table 4. Initial parameters of the proposed hybrid algorithm.

Initial population	100
Number of iterations	100
Number of groups	10
Crossover rate	20%
Weekly interest rate	0.7%
Number of runs	10

Table 5. Results of solving the model.

Minimum cost of initial generation	10^6 ×2.62
Minimum cost of final generation	10^6 ×2.35
Processing time	3 seconds
Succes rate	60%

6 | Conclusion

This study aimed to present a new model for supplier selection and optimizing the NPV of procurement in the logistics department of a construction project. We designed and presented a hybrid metaheuristic algorithm that combines the shuffled frog leaping and GA and applied the results to the modeled case study of a real-world construction project. The model introduces the costs of various activities, such as quality control, which strongly affect the overall quality of the project, in mathematical form and considers the impact of the NPV or costs on the supplier selection process. Given the complexity of the model, a hybrid metaheuristic model was proposed to obtain the results within a reasonable timeframe. In the end, the model was successful in obtaining optimal results at an acceptable time. The authors expect the model to enable project planners and decision-makers to evaluate select the best possible suppliers, both in terms of the number and costs, from among the available candidates. Moreover, the model presents a cash-flow diagram of the project, including the inputs and outputs along with exact dates to project board and helps the board members to monitor the financial state of the project at all times to ensure that any managerial decisions can be made in a timely manner. Lastly, the model can be used as a reliable basis for budget allocation and financing in real-world construction projects.

6.1 | Limitations and Future Research Directions

One of the shortcomings of this study was the assumption that the budget would be unlimited and no restriction was placed on the costs covered in each period. Since one of the main goals of studies like this is to create models that are usable by industries, in future research, certain monetary restrictions may be imposed on the project's cash-flow to better reflect real-world conditions. Finally, researchers may work on expanding the model developed in this study and using it in more complex project in order to achieve a better understanding of the various time situations and possible crises, improve the methods of evaluating and selecting suppliers, determine the most appropriate time for signing contracts with suppliers, and assess the impact of suppliers on the end date of projects.

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